Site: Maline Creek
ID # MOD980631162
Break: 2.4
Other: N/D

Engineering Design, Specifications, and
On-Site Technical Assistance
for Covering Waste Asbestos

U.S. Army CRREL
Hanover, NH

United States Environmental Protection Agency

EPA

Region I

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NEW ENGLAND REGIONAL LABORATORY

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LOWELL ROAD SITE
Hudson, NH

Engineering Design, Specifications and
On-Site Technical Assistance
for Covering Waste Asbestos[1]

U.S. Army CRREL
Hanover, NH

Introduction

This report describes the design work and on-site technical assistance given to EPA-Region I by the U.S. Army Cold Regions Research and Engineerng Laboratory (CRREL), under the Superfund sponsorship, for the containment of waste asbestos at the Lowell Road site in Hudson, NH. The purpose of the containment was to remove asbestos waste on or near the ground surface from potential health hazard, by means of permanent or long-term burial on-site. Asbestos particles, when airborne, have been shown by the National Health Service to be hazardous to the health of persons breathing the air in which they are carried.

The design work and technical assistance covered the period May 1985 through December 1985. Active restoration of the site was accomplished by EPA from 9 September to approximately 30 September 1985. Until August 1985 Gordon Bullard, Engineer, was the On-Scene Coordinator (OSC) for EPA; thereafter the OSC was Paul Groulx, Environmental Scientist.

The engineering design work was performed for EPA by Richard McGaw, P.E., Research Civil Engineer, assisted by Dr. Iskandar (Alex) Iskandar, Research Soil Chemist, and Susan R. Bigl, Research Physical Scientist, under Interagency Agreement No. DW 21931501 between the U.S. Army Corps of

[1]For U.S. Environmental Protection Agency - Region I (New England).

Engineers and the Environmental Protection Agency. CRREL is a Corps of Engineers laboratory specializing in solving problems involving snow, ice and frozen ground.

Site Characteristics

The waste asbestos site on Lowell Road, an arterial state highway in Hudson, NH, comprises approximately 50,000 sqft of residential area underlain by waste asbestos sheet products. Figure 1 indicates the location of the Lowell Road site within the town of Hudson. Three residences on the site are currently situated on fill composed of the waste asbestos. The inhabitants of each of these residences were evacuated at EPA expense during the active restoration phase.

A year-round brook flows under Lowell Road and enters the site via an existing masonry culvert, crossing the site from east to west (Fig. 2). The northern bank of the brook is bordered by the nearly flat and extensive rear lawn of the central residence, No. 11 Lowell Road. The original surface of this lawn was approximately 2 ft above the stream bed, and was underlain by waste asbestos within a few inches of the surface. The brook level during the Spring period reached almost to the elevation of this lawn.

The southern bank of the brook is steep and wooded, rising approximately 20 ft above the stream. In the first 100 lineal ft beyond the culvert, this bank is a 10-ft high outcrop of exposed asbestos sheets and other asbestos waste products which is being eroded and undercut by the stream flow. The nearly level upper surface of this deposit is occupied by the house, lawn, and driveway of No. 13 Lowell Road.

It was known that the New Hampshire State Highway Department had prepared specifications and drawings for relocating the paved area of Lowell

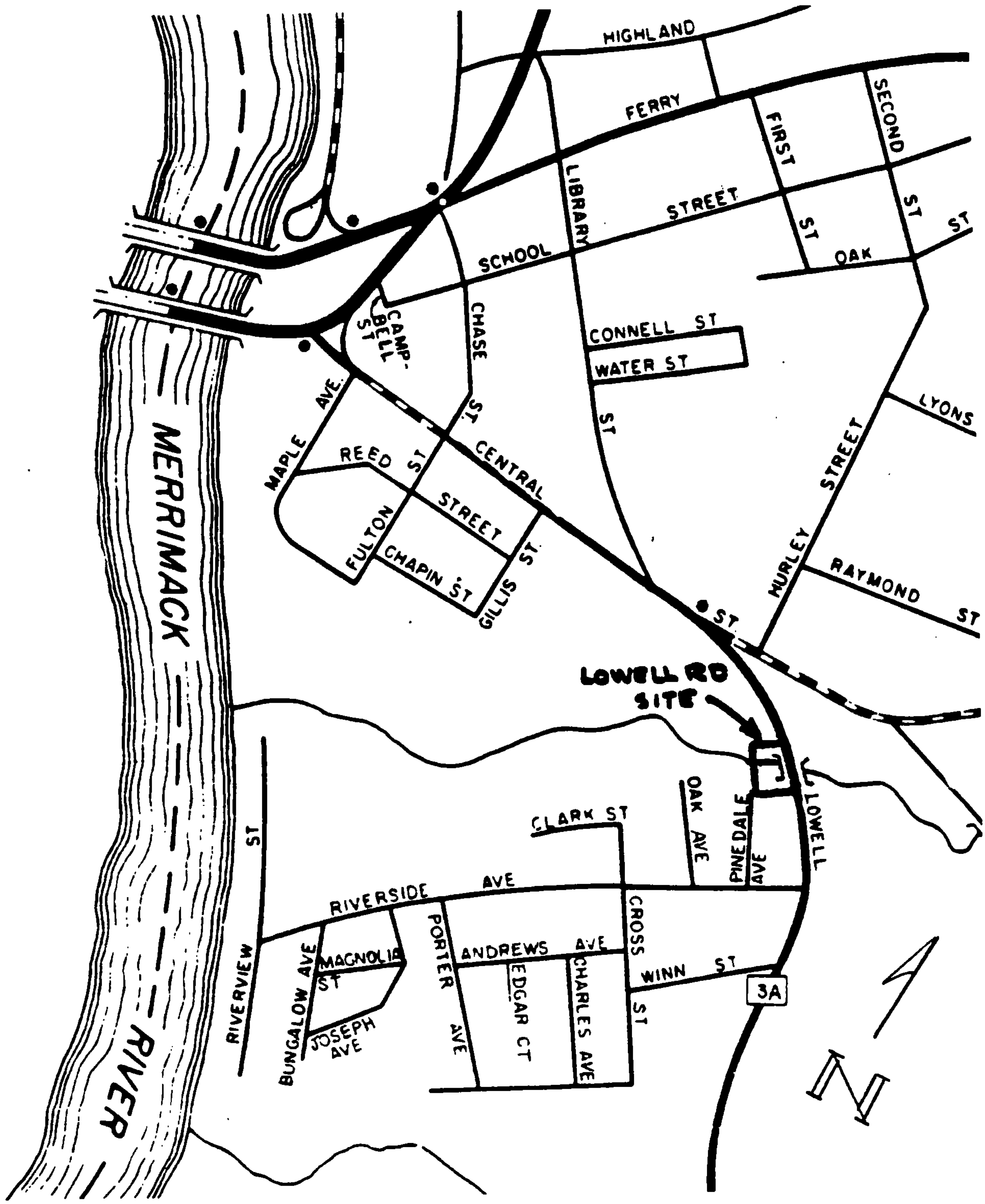

Figure 1. Location of Lowell Road Asbestos Site in Hudson, NH.

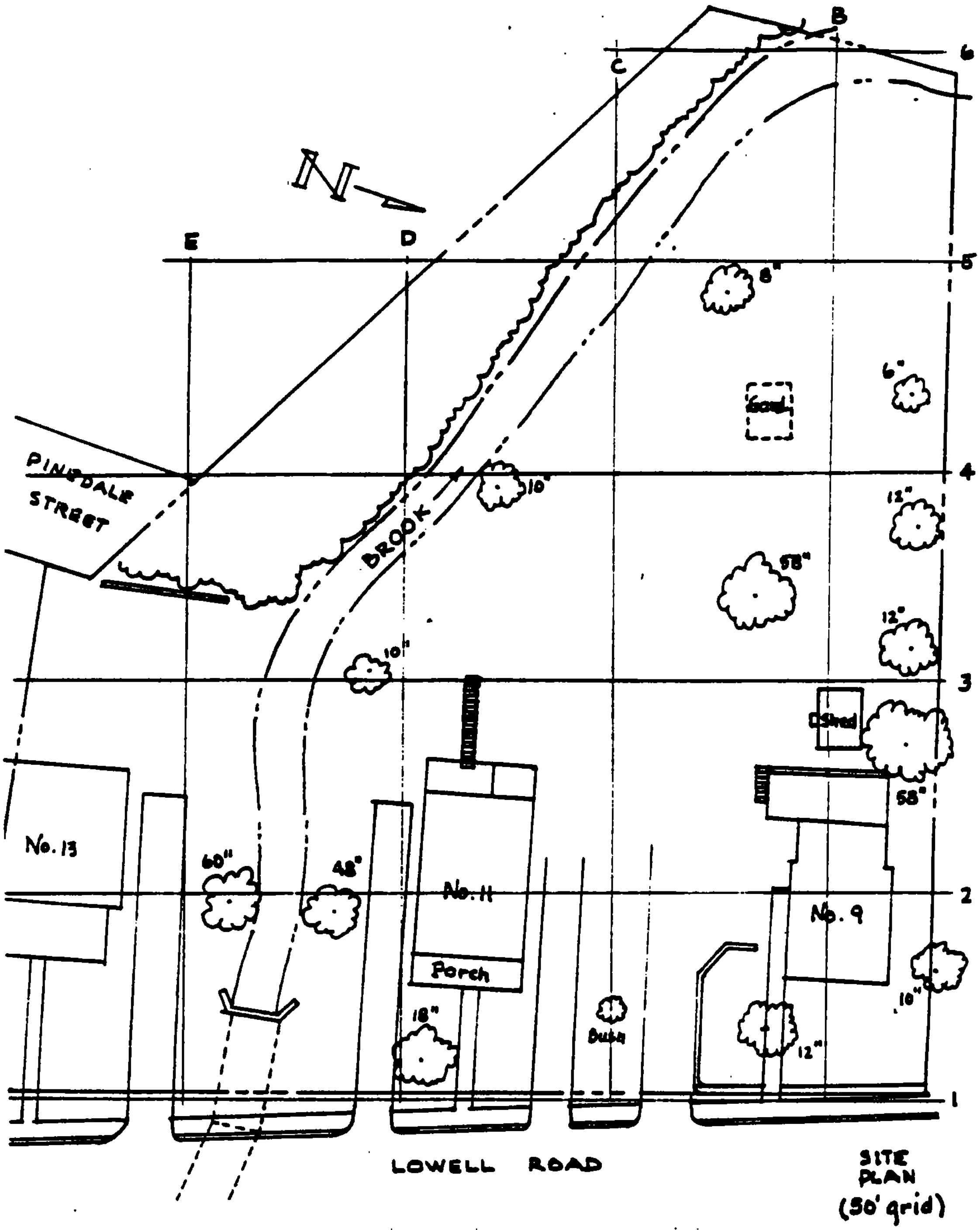

Figure 2. Sketch of the Lowell Road Site.

Road some 20 ft to the east (farther from the site) in the near future. A portion of these plans involved removing the existing masonry culvert and replacing it with a metal culvert to carry the brook beneath the highway. Because of these planned developments, both the engineering design and the site restoration by the EPA were required to be coordinated with the proposed revisions to the highway.

Design Concept

As with other waste disposal sites in the town of Hudson, the primary design principle was to contain the waste asbestos by means of long-term burial with appropriate soil layers. A soil cover and surface treatment were selected that would restrain the asbestos-containing particles from moving toward the surface for at least 100 years under the effects of freezing and thawing. It was also important that the surface treatment be such as to eliminate erosion of the burial layers through the actions of stream flow or surface runoff.

The vertical bank of exposed asbestos presented a special problem. The material could not be removed or disturbed without possibly endangering the stability of the dwelling built on the deposit; the local topography strongly suggested that the deposit extended with similar thickness directly under the house foundations. One solution contemplated was the construction of a permanent cribbing along the edge of the brook to support the exposed material and to relieve the erosional potential of the flowing water at its base. Retention of the root structure of a mature elm tree growing from the bank itself was also considered as an aid in the retention of asbestos particles.

Such a crib structure would have required secure anchoring below the level of the stream bed by means of steel or wooden piling. However, the driving of these piles would likely have caused shear failure or localized slippage within the apparently unconsolidated asbestos deposit beneath the house at No. 13 Lowell Road. It was feared that such slippage would result in a tilting of the structure in the direction of the brook. For this reason, the concept of a crib retaining wall was discarded.

We then recommended that a 75-ft extension of metal culvert be placed on footings within the brook itself and backfilled to the height of the exposed vertical bank of asbestos. By this means, the exposure of the deposit would be eliminated with little or no disturbance of the deposit itself.

In consultations with Russell Davis, Engineer with the New Hampshire Highway Department, this was the solution agreed upon to contain the exposed asbestos. EPA also agreed to abide by his recommendation to join the metal culvert with the existing masonry culvert and to place a 30-in. storm drain and concrete manhole alongside the culvert extension. This drain would carry storm water from catch basins in Lowell Road. During the restoration it was also used to divert the brook to allow placement of the culvert extension.

These latter requirements resulted in considerably more excavation of waste asbestos from the lower (north) side of the stream bank than would have been required had the storm drain not extended entirely to the end-wall of the culvert extension. The additional excavation required a higher degree of precaution against contamination of construction personnel, together with truckage of the excess asbestos material to an approved dumping site. Nevertheless, the final result was a safer and longer-term solution to the containment problem than a pile-supported crib would have been.

The final design also included a stonework masonry endwall within the back-lawn area of the central residence, utilizing economical standard highway department procedures for the masonry. The end wall treatment together with other design features effectively restored the secluded picnic-ground atmosphere that existed prior to the construction work. In residential areas in particular, the recovery or replacement of the natural attributes that give the land its esthetic or other value is believed to be an important factor in restoring an asbestos site to a permanently safe and usable condition. This goal was accomplished to a large degree at the Lowell Road site.

Specifications and Description of Cover Used

In general, the selection of an appropriate depth of cover to contain waste asbestos material permanently below the surface in northern areas such as Hudson, New Hampshire, is based on the winter climate and the degree of exposure to snow. Winter climate for the general area is characterized by a 30-year mean air freezing index, which is defined as the total number of degree-days below freezing in an average winter. The index for Hudson is derived from temperature records measured by the National Weather Service at Nashua, New Hampshire, for the period 1951-1980. Its value is given as 665 degF-days.[2]

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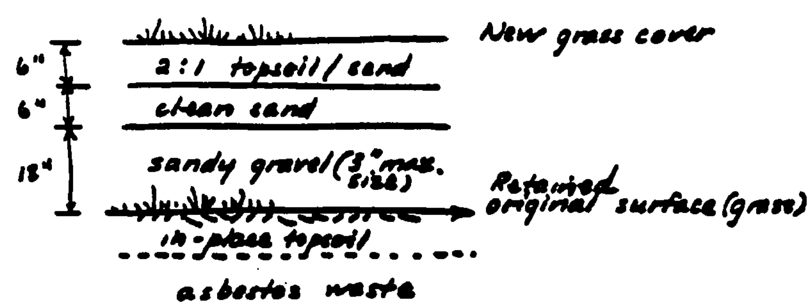
[2]Monthly Normals of Temperature, Precipitation, and Heating and Cooling Degree Days, 1951-1980, New Hampshire, in Climatography of the United States No. 81 (By State), National Climatic Center, Asheville, NC (Dept. of Commerce), Sept. 1982.

The danger of buried asbestos particles being returned to the surface of the ground, where they may pose a renewed health hazard, is a function of the number of times the asbestos deposit is penetrated by winter freezing temperatures. A criterion of 10 freezings per century, on the average, is judged as being sufficient to retain the asbestos permanently below or within the burial layers of soil, based on an estimate of the upward movement likely to result from each freezing and thawing cycle. To design for this criterion, an air freezing index greater than the mean value is utilized, one based on the 3 coldest years in the 30-year period. The probability that this larger freezing index will be exceeded in 100 years is approximately 10%; the probability that frost penetration will exceed the depth of cover based on this freezing index is also 10%, for an average of 10 times per 100 years.

An average yearly snow depth creates an insulating effect which reduces the effective freezing index at the ground surface and also reduces the required depth of burial.

The complete rationale for selecting the appropriate depth of cover is given in the Appendix to this report. To summarize, it recommends that the design depth of cover for Hudson, NH be 30 inches, utilizing the profile illustrated here:



The new grass cover could have been sown. However, because the price for laid sod, including labor, was within 10% of the price for sowing a lawn in the Nashua/Hudson area, it was decided to gain the immediate protection against erosion that an established lawn cover provides. Sod was therefore used for all but a small area at the rear of the site which was heavily shaded.

A garden area within the grassed portion was given special treatment. Organic topsoil mixed with fertilizer and some sand was placed directly over the formerly tilled surface and brought to the new level of the adjacent grassed area. The garden could then be culivated as before but with no danger of intercepting the underlying asbestos.

A sloping bank adjoining the lawn at the rear of the central dwelling, in which flowers and shrubs were growing, was also specially treated. A nurseryman was brought in to lift out the plants, and after visible pieces of sheet asbestos were disposed of, to replace the plants in a new 18-in. layer of fertilized potting soil. This procedure was also used for replacing the foundation plantings at No. 13 Lowell Road.

The soil cover over the culvert extension completely enclosed the outcropping bank of asbestos sheets. Over the center of the pipe the cover consisted of approximately 12 in. of sandy gravel topped by 12 in. of clean sand; the sand layer was left uncovered. Nursery shrubs and evergreen trees with shallow root systems were planted in this area following an application of fertilizer to the planting sites, to serve as a permanent screen between the adjacent properties. Short sections of chain-link fence were placed at each endwall of the culvert extension to protect children of the neighborhood from injury by falling into the brook.

The concrete-block foundation of a small summer house at the rear of No. 11 was increased in height so that the house would not be inundated by run-off from the nearby lawn area, the final elevation of which was 1 ft higher than it had been previously. The doorway and the elevation of the floor slab were also raised.

Finally, prior to placement of the burial layers, crushed stone 3 to 5 inches in diameter was hand-placed around the root areas of the trees that had been retained, to a diameter of approximately one-half the full width of the crown and to a level of 2 ft above the original surface. The assurance of the nurseryman was received that this treatment would sufficiently protect the roots from burial stress so that individual retaining walls would not be required for separating these trees from the raised lawn area.

Crushed 5-in. stone was also placed along 200 feet of the bank of the brook, to protect against erosion during periods of high water.

On-Site Technical Assistance

A total of seven on-site inspections of the Lowell Road site were made between the dates of May 3 and November 6, 1985. Five of these also included visits to the Shady Lane site in Nashua and to several other asbestos sites within the area.

A summary of the inspection trips performed during the project period is included as Table 2. During these visits engineering advice and other technical assistance were given to the On-Scene Coordinator by the design engineering staff (McGaw and Iskandar).

Table 2. On site inspection trips.

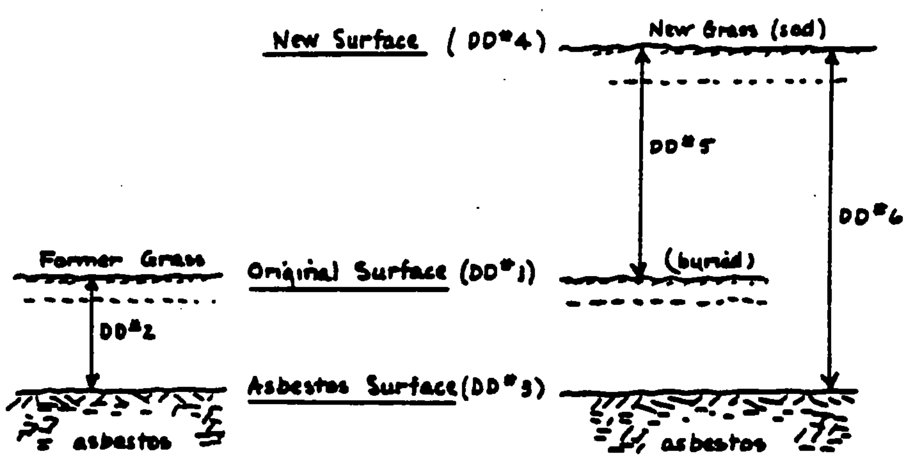
Travel Date	Persons Consulted	Sites Visited: Lowell Road	Sites Visited: Shady Lane	Sites Visited: Other	Weather	Remarks
1985 May 3 (Fri)	Groulx, Sprague	X	X	Exxon, Fimble, Sprague, Pointer, Bursey, Mattarazo	Rain	Initial inspection; checking erosion at restored sites.
July 22 (Mon)	Bullard, Sprague, Davis	X	-	NH Hwy Dept.	Clear	Discussed pipe design.
Aug 1 (Thur)	Bullard	-	X	—	Cloudy	Taped trees to be retained.
Aug 21 (Wed)	Bullard, Sprague, Carl (Sweeney's office)	-	X	—	Clear	Discussed State closing of landfill.
Sept 9 (Mon)	No travel; began reconstruction at Lowell Road site.					
Sept 13 (Fri)	Groulx	X	-	—	Clear	Excavating for pipe.
Sept 19 (Thur)	Groulx, Sprague, Sweeney, Nashua officials	X	X	Mayor's office, Nashua	Clear	Discussed coordination with State & closing of Landfill at Shady Lane; pipe in place at Lowell Road.
Sept 23 (Mon)	No travel; began reconstruction at Shady Lane site.					
Sept 25 (Wed)	Groulx, Sprague, Nashua officials: Mayor, Freeman, Dorsey, Alderman, and parents.	X	X	—	Cloudy	Planting trees, shrubs at Lowell Road site; chipping brush at Shady Lane site; evening informational meeting at Shady Lane school.
Oct 2 (Wed)	Groulx	-	X	—	Cloudy	Spreading sand and loam.
Oct 17 (Thur)	Groulx, Sprague, Drew, Mike, Dennis	X	X	Niquette Dr., Nowell Road	Clear	Post-reconstruction inspections.
Nov 5 (Tue)	Groulx	-	-	EPA (Lexington)	Rain	Checked photos.
Nov 6 (Wed)	Goulx	X	X	EPA (Lexington), Nowell Road, Russell Ave., N. Bank, S. Bank	Rain	Checked photos of Lowell Road and Shady Lane work; inspection of new sites.

Design Drawings (Initial and As-built Conditions)

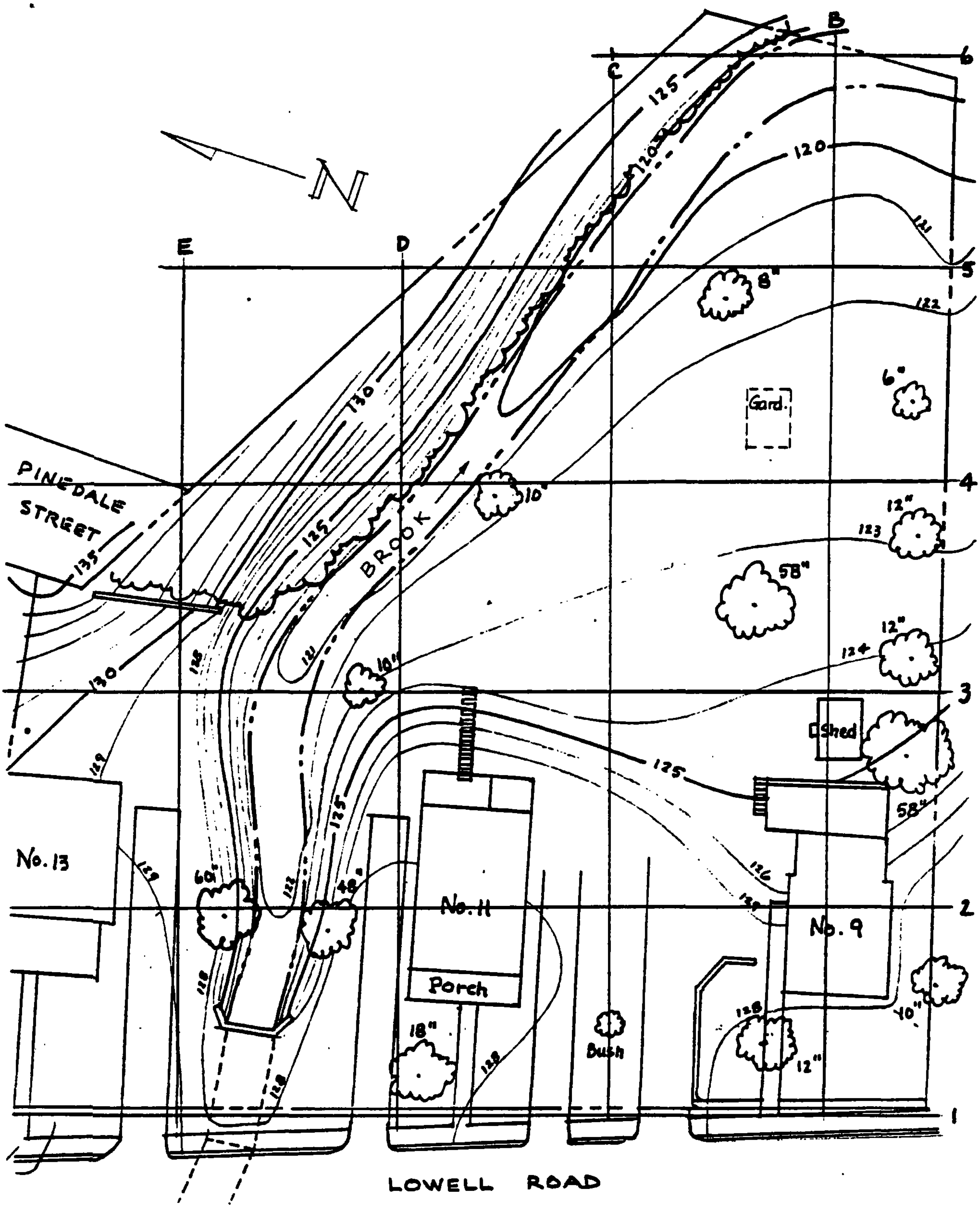
Engineering information developed and utilized by the writer in the design of the permanent cover for the Lowell Road site is summarized in the form of six design drawings, which are attached to this report. These drawings illustrate the topography of the original and final ground surfaces, the topography of the surface of the asbestos deposit, the depth of cover over the asbestos both before and after restoration, and the thickness of the soil materials added to the site.

The drawings and the information presented here are in addition to site plans and other drawings furnished by the EPA and by the State of New Hampshire. These latter are on file at the EPA and need not be reproduced in this report.

The legend for the design drawings (DD Nos. 1 to 6) is illustrated below:



DD No. 1: elevations of the original surface, in feet, (prior to restoration). These elevations are based on a topographic plan drawn by Roy F. Weston, In. (SPER Division) dated 9 July 1985. DD No. 1 represents a corrected version, inasmuch as their plan showed the 120 ft to 123 ft



Design Drawing 1. Elevations of the original surface (ft).

contours incorrectly positioned as judged by the comparative location of the brook and by a later survey. The north-indicating arrow was also pointed toward the south of the site.

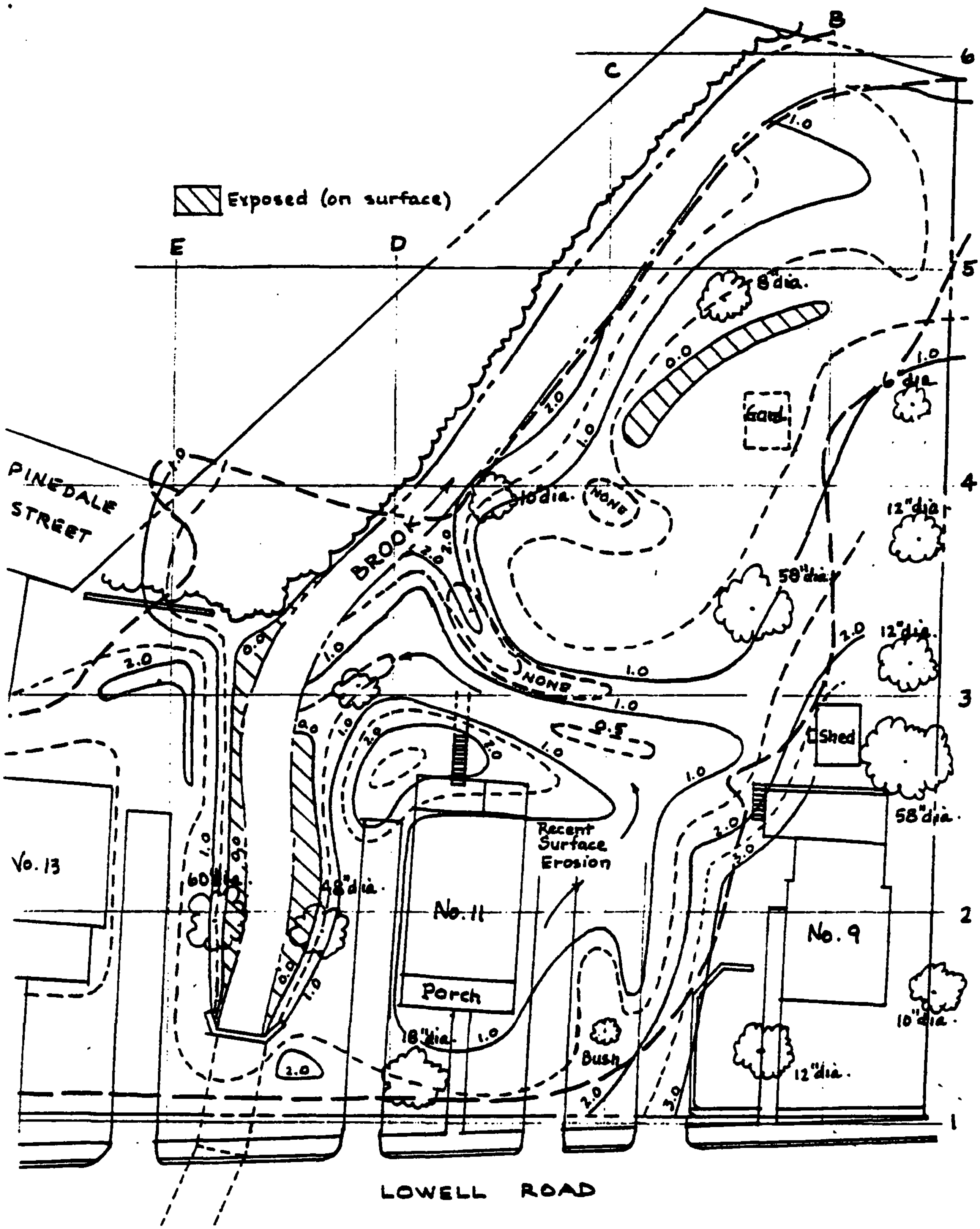
The grid indicated on DD No. 1 measures 50 ft on a side and represents survey points on the ground surface. The scale of this and the following design drawings is approximately 1 in. = 30 ft.

<u>DD No. 2</u>: <u>depth of the asbestos material below original ground surface, in feet</u>. This information is based on a sampling location map produced by Roy F. Weston, Inc. and dated 2 July 1985. This map indicated the location of approximately 75 sampling sites within the grid area, and had been annotated with the depth at which asbestos was first encountered at each sampling point. The heavy broken line shows the approximate lateral extent of the asbestos deposit.

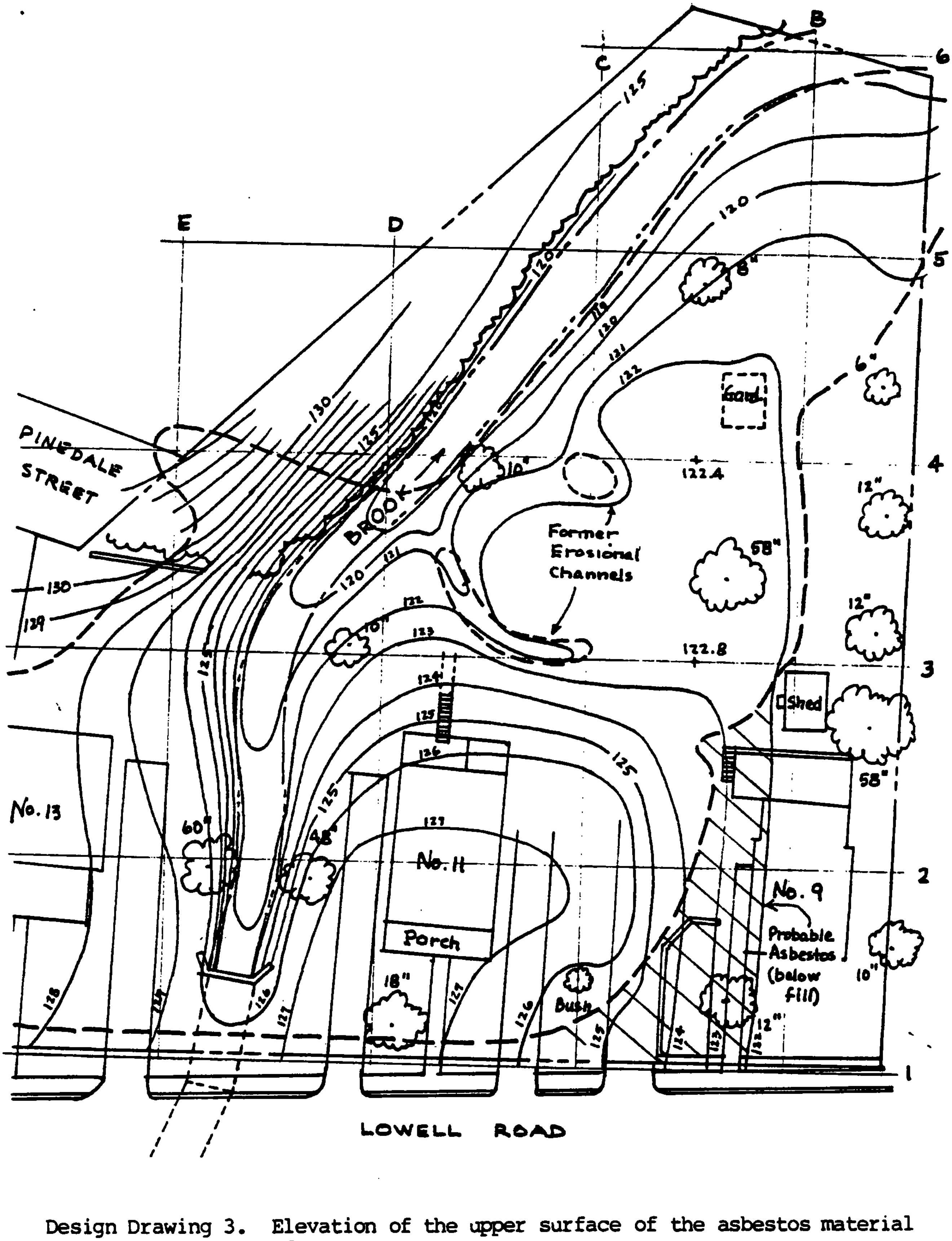
Two small areas were found where no asbestos was encountered (indicated by the word "NONE" near the center of the site). Furthermore, no asbestos was found within 30 in. of the surface near No. 9 Lowell Road. Later drawings suggest a deeper, buried layer of asbestos beneath this dwelling.

Hatched areas indicate exposed asbestos along both sides of the brook immediately downstream of the masonry culvert, and in an area of the back lawn near the garden. Incipient exposure of asbestos at the rear of No. 11 (i.e., asbestos within 0.5 ft of the surface) was also evident, being brought about by recent surface erosion associated with runoff from the driveway area to the north of No. 11.

<u>DD No. 3</u>: <u>elevation of the upper surface of the asbestos material, in feet</u>. This information was deduced by combining the elevations shown on DD



Design Drawing 2. Depth of the asbestos material below original ground surface (ft).



Design Drawing 3. Elevation of the upper surface of the asbestos material (ft).

No. 1 and DD No. 2. Establishment of this surface is important at each asbestos waste disposal site, in that the configuration of this surface largely determines the distribution of subsurface drainage from the site following restoration.

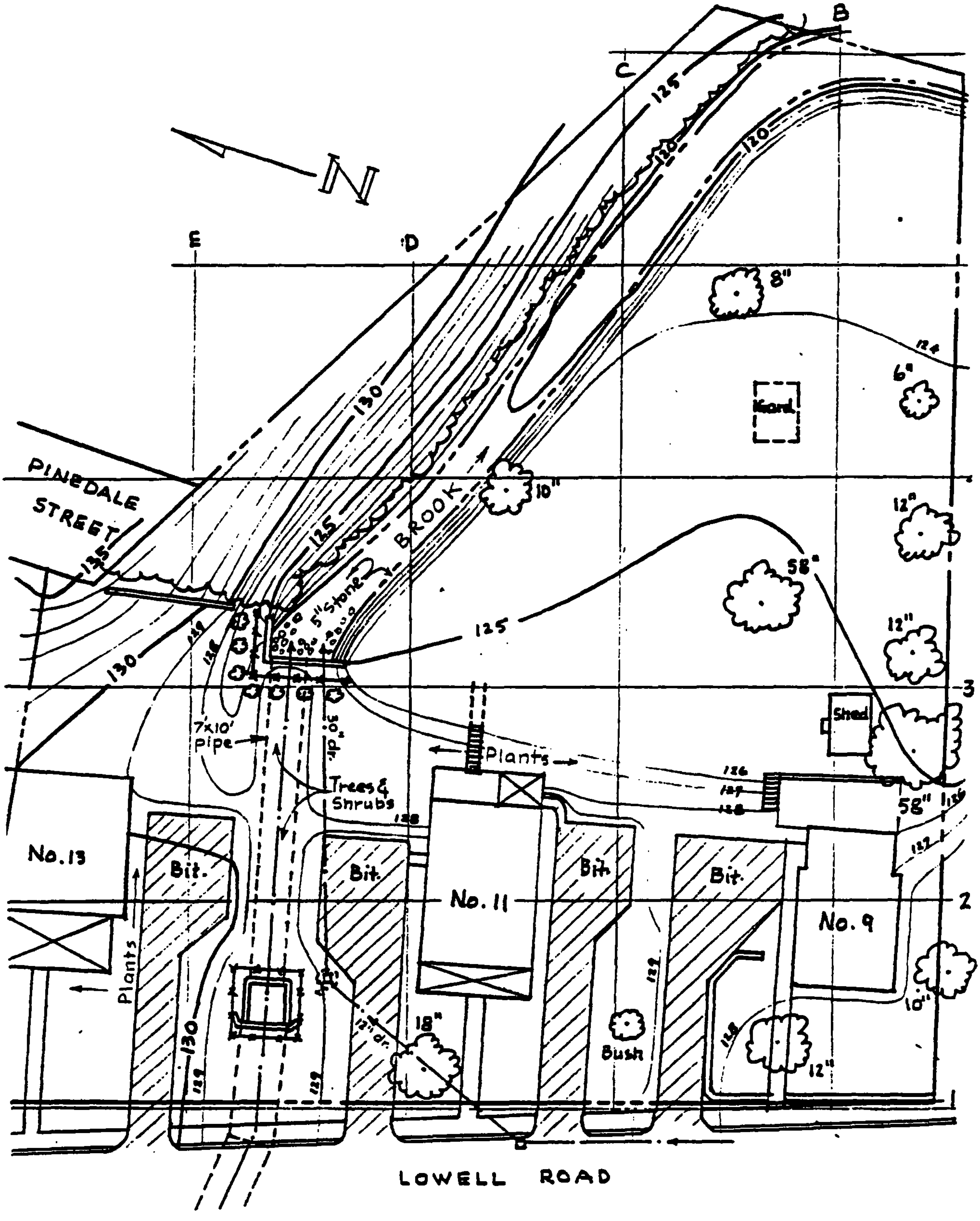
This drawing suggests that dumping of the asbestos waste took place from the right-of-way of Lowell Road on both sides of the brook. Two buried erosional channels which are cut into the low-lying plateau of asbestos beyond the main lobe seem to be at the locations where no asbestos was found in July 1985. Evidently the hazardous material had been eroded away prior to the construction of the original lawn.

These channels today enhance the drainage of ground water from the restored lawn area, and are a positive sign that future erosional problems should not develop.

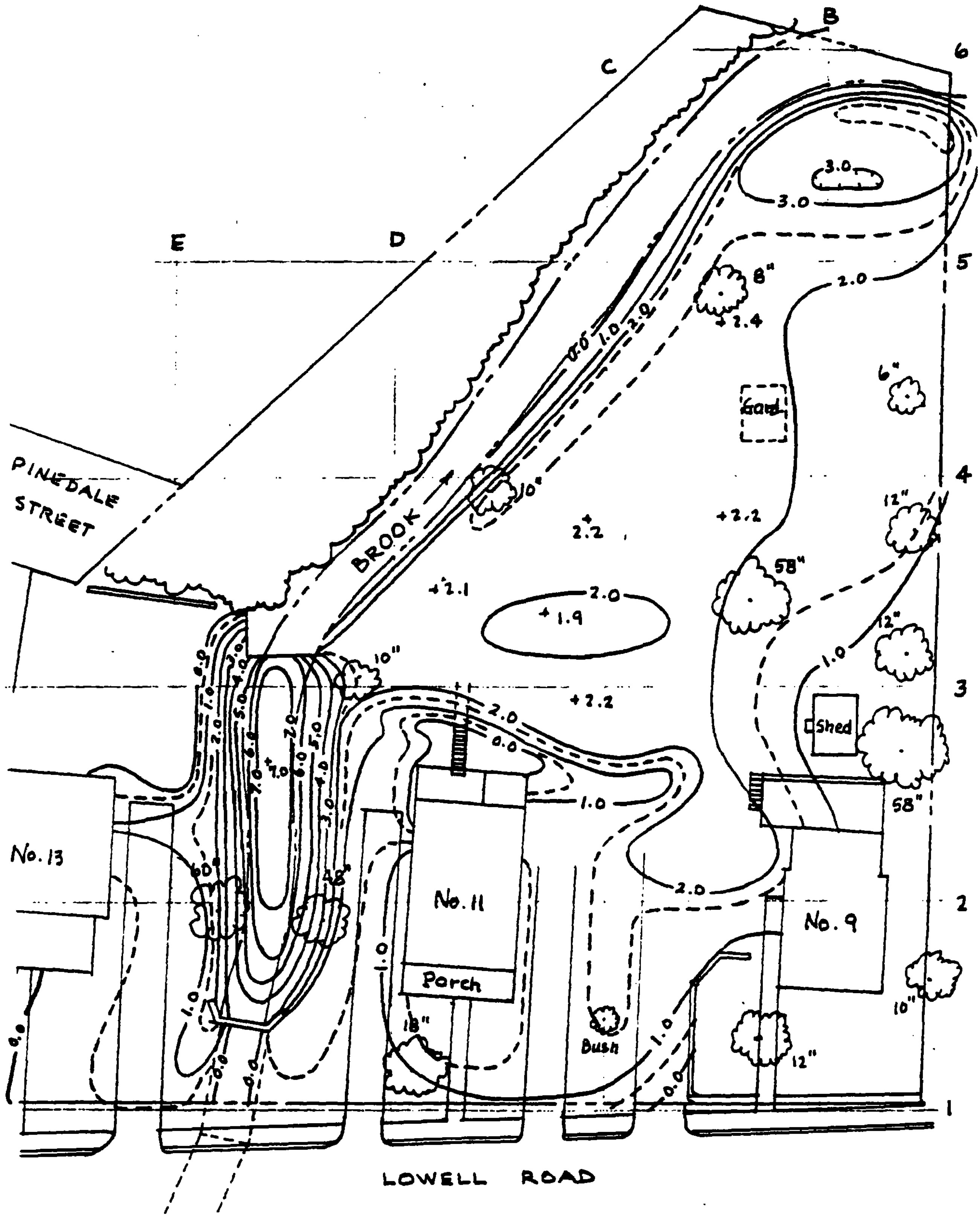
DD No. 3 also shows the probable elevation of the surface of the asbestos under the parking area of No. 9 Lowell Road, deduced from the manner in which the asbestos waste appears to have been dumped. It is probable that clean fill was placed over the asbestos when the house at No. 9 was constructed.

DD No. 4: elevations of the as-built surface, in feet. This information is based on a topographic plan prepared by O.H. Materials Co., dated 25 October 1985, following the restoration of the site by the EPA. The locations of the culvert extension (7 ft x 10 ft pipe), the 30-in. storm drain, the two new endwalls, and the paved driveway areas are indicated in the drawing.

DD No. 5: depth of material added, in feet. The combined thickness of gravel, sand, topsoil, and sod added to the lawn areas of the site; or



Design Drawing 4. Elevations of the as-built surface (ft).

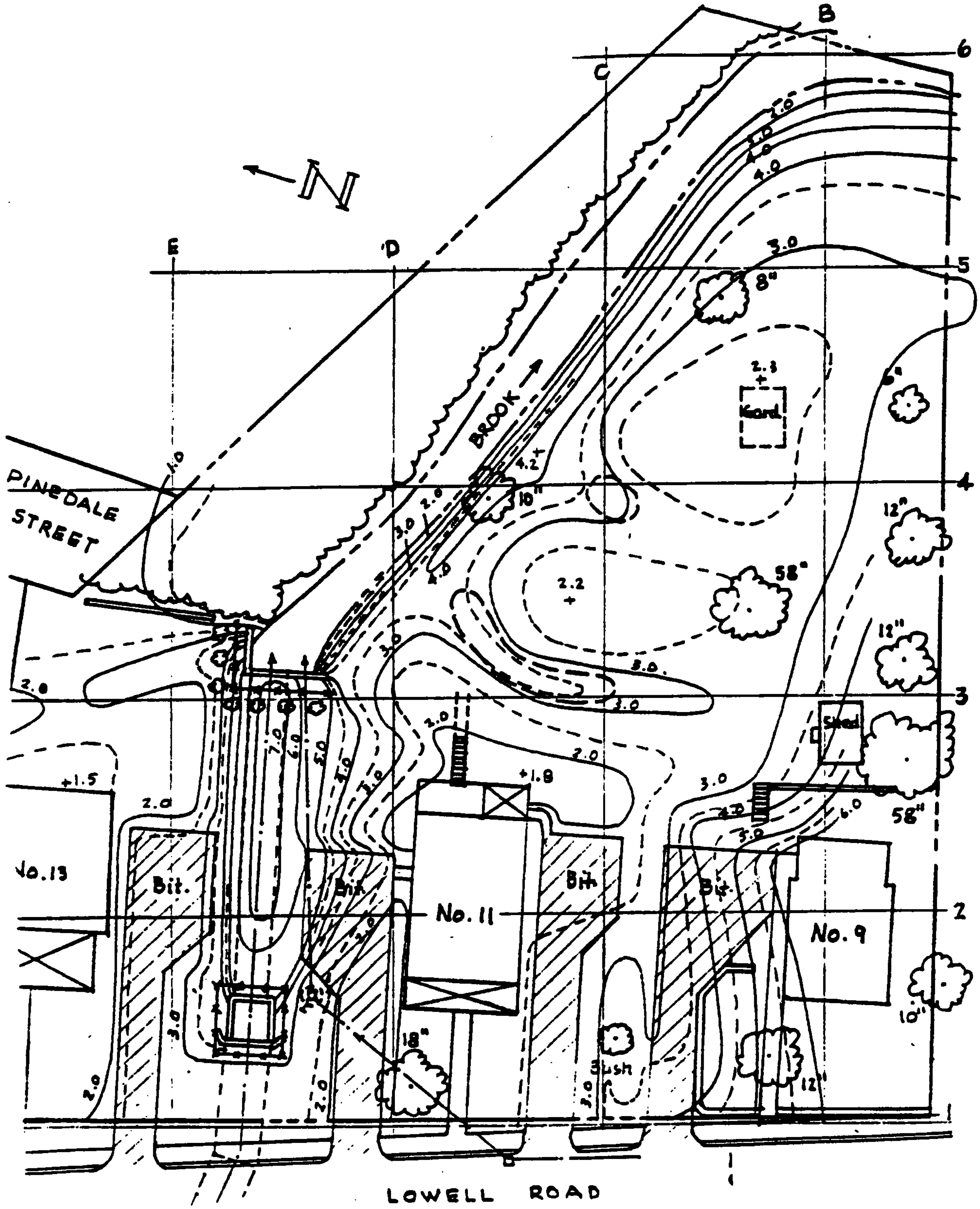


Design Drawing 5. Depth of material added (ft).

of gravel and pavement to the driveway areas; or of gravel and stone to the streambank areas; or of backfill around the culvert extension: these values were obtained as the difference in elevation between the as-built surface (DD No. 4) and the original surface (DD No. 1). Except for a portion of the backfill which was obtained on-site, all of the material indicated was brought to the site by means of trucks.

DD No. 6: final depth of cover over the asbestos material, in feet. Following restoration, the full thickness of soil and grass (or pavement or stone) over the asbestos material was obtained as the difference in elevation between the as-built surface (DD No. 4) and the surface of the asbestos (DD No. 3).

As illustrated, the minimum depth of cover in the lawn area is approximately 2.2 ft (26.5 in.) including the sod turf; as expected, the effective depth of cover is somewhat greater over the buried drainage channels and in the vicinity of the culvert extension. Overall, DD No. 6 indicates that the conformance of the site restoration to the design standard (minimum cover 30 in.) is excellent.



Design Drawing 6. Final depth of cover over the asbestos material (ft).

APPENDIX

Rationale for Determining Soil Depth Cover for Waste Asbestos in Nashua and Hudson, New Hampshire

APPENDIX

Rationale for Determining Soil Depth Cover for Waste Asbestos in Nashua and Hudson, New Hampshire

Introduction

This rationale is intended to provide preliminary guidance and relates specifically to the Shady Lane and Lowell Road asbestos burial sites in Nashua and Hudson, New Hampshire, respectively. It is based primarily on laboratory and field experience with freezing and thawing of soils containing inclusions.

The primary objective of this design is to determine the amount of soil cover needed to significantly reduce the number of times that the frost zone penetrates the soil ladened asbestos material. The main concern is that if the soil with asbestos or simply asbestos is allowed to freeze and thaw, a process called sorting may bring the asbestos pieces to the ground surface and expose the environment to their hazardous effects.

When a moist soil freezes, water within the soil is drawn toward the freezing front, i.e. where freezing is taking place. A mass of ice is formed within the voids of the soil which tends to push the particles apart. Normally, the direction in which the particles of soil are most free to move is toward the surface, resulting in frost heave.

If a source of free water is available, such as a water table within 10 ft. of the surface, the ice masses will continue to draw water from below, eventually forming what are typically termed ice lenses. Significant volume changes occur in a soil when ice lenses form. Not only will the ground surface rise (i.e., heave) anywhere from 1 inch to 12 inches during a winter season, but individual particles will be moved closer to the surface (Washburn, 1973; Corte, 1969; Kaplar, 1965).

During the subsequent spring thawing period much of the frost heave will be recovered: the ground normally subsides more or less back to its former volume. In order for this to happen, excess water stored in the ice lenses must somehow drain away; but until it does, the soil will be soft and easily deformable.

Because the soil is temporarily soft, the finer (smaller) particles of soil tend to move down and under the larger particles, holding them in the positions to which they moved when they were frozen. When the soil finally becomes more stable in the summer, the larger particles end up closer to the surface than they were the previous summer. Because this sorting process takes place year after year, stones and other particles may sometimes move significant distances toward the ground surface. The process is likely to be accelerated when the particles approach the ground surface, because this zone experiences multiple freeze/thaw cycles during a single winter season.

It is assumed that asbestos chunks and particles are likely to be affected by the seasonal processes of freezing and thawing in much the same manner as stones and other natural inclusions. Freeze/thaw cycles may have two types of long-term effects on the permanent containment of waste asbestos as a result of:

a. The differential movement of foreign matter toward the surface with each cycle of freezing and thawing may eventually bring chunks and pieces of asbestos to the ground surface and thereby return them to the external environment; and

b. Asbestos scraps (broken boards, chunks, even cemented pellets) may be broken into smaller pieces as moisture held within the scraps freezes, so that when they reach the surface they are sufficiently small to be environmentally hazardous.

A prospective long-term means of preventing asbestos particles from moving toward the surface through the freezing and thawing process is to make sure that they are never frozen. However, because economic considerations must be taken into account, the design presented here is based on an attempt to contain the waste asbestos below the ground surface for a minimum period of 100 years. The actual safe lifetime is probably well in excess of 100 years, provided the removal of covering material by erosion or human activities is effectively controlled. This design assumes a turf cover with a well established root zone. It does not include a safety factor to account for construction or garden cultivation.

The procedure used here to select an appropriate depth of soil cover to contain asbestos material below the surface in southern New Hampshire is a modification of a procedure developed by the U.S. Army Cold Regions Research and Engineering Laboratory (CRREL) for designing pavements against failure caused by freezing and thawing (Dept. of the Army and Air Force, 1985). It employs the use of the modified Berggren equation for layered systems, which is also discussed in Lunardini (1981).

This procedure has been validated with more than 30 years of experience by the Corps of Engineers in airfield and highway design. The technique has been shown to yield excellent results, when applied to in situ phase changes in soils (Dept. of the Army and Air Force, 1966; McRoberts, 1975).

Basically, the ground freezes because of the removal of heat. It is therefore clear that the depth of frost penetration below the surface is related to the meteorological variables that affect heat loss and the physical properties of the soil. The major variables are (1) the severity of the winter air temperatures, and (2) the amount of snow cover. The severity (coldness) of the air temperature is expressed in terms of an <u>air freezing index</u> for each winter. The efficiency of thermal transfer between the air and the ground or snow is expressed in terms of an n-factor, where n is a fraction between 0 and 1. In combination, the two parameters result in a <u>surface freezing index</u>, which is a measure of the amount of heat leaving the ground over an entire winter. The manner in which these values are utilized to calculate the suggested depth of cover for safe burial of waste asbestos is described below.

<u>Air Temperature</u>

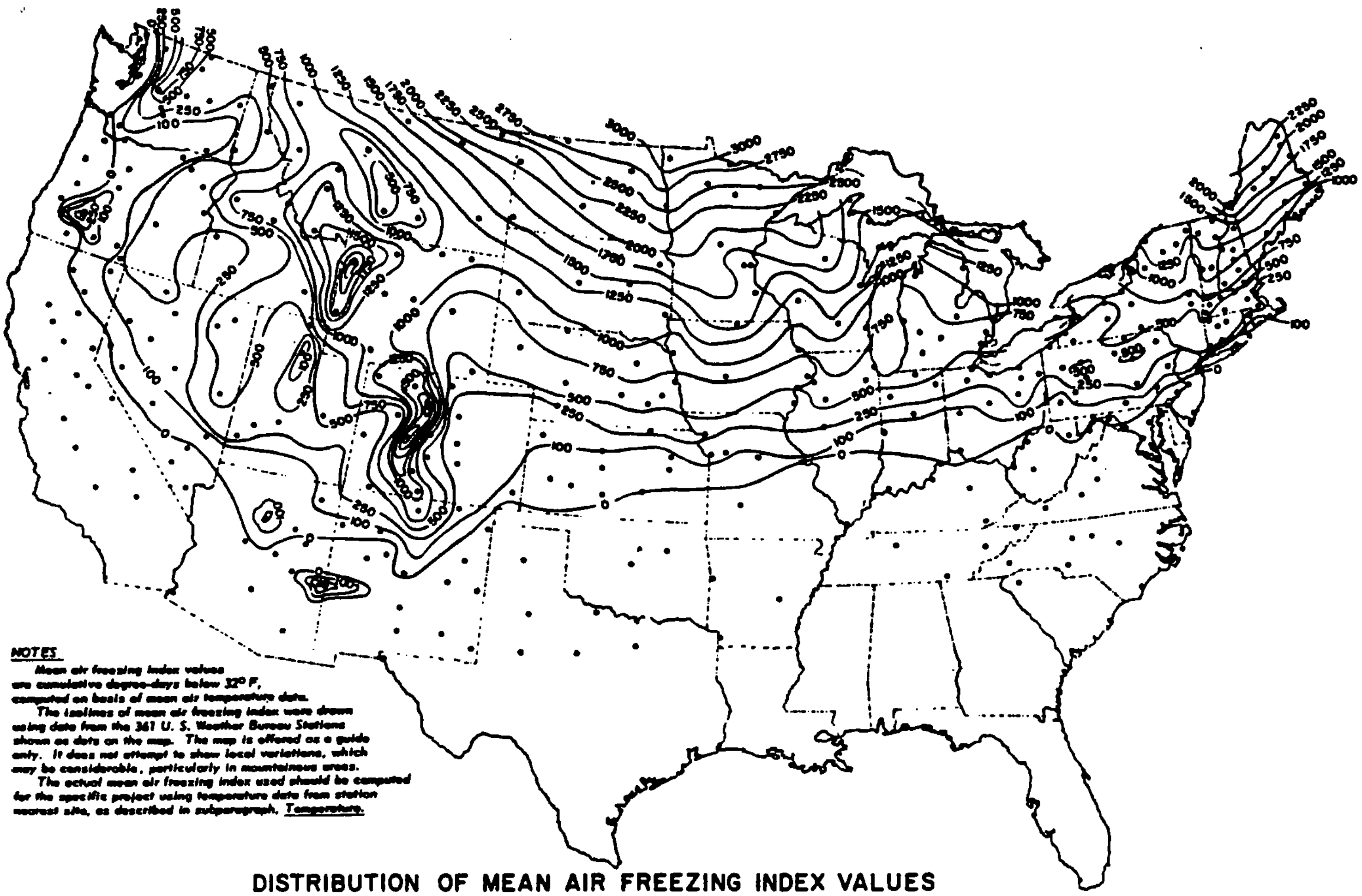
The air freezing index for a given area is the total number of Fahrenheit degree-days below freezing (32°F) for a winter season. It is calculated as discussed in the Department of the Army Technical Manual 5-852-6 (1966). The calculation procedure is similar to that used for the more familiar "heating degree-days," except that for heating purposes the winter temperatures are subtracted from 65°F.

The average daily, or mean monthly, air temperatures used for these calculations are those measured by the nearest official station of the National Weather Service. The Weather Service publishes a monthly record of these temperatures (U.S. Dept. of Commerce, 1950-1980). At 10 year intervals, they also publish 30-year normals of various climatological parameters (U.S. Dept. of Commerce, 1985).

Nashua, New Hampshire, is one of the weather stations for which an extended record of air temperatures is available. An accurate record of many years duration is desirable because it shows not only the average temperatures likely to occur in a winter, but the warmer and colder years as well and the frequency with which they occur. The temperatures in a region are normally considered to be those of the central station with adjustments for exposure; the temperatures at Nashua are assumed to be representative of those at Hudson, New Hampshire.

For the Nashua/Hudson area the air freezing index, averaged over the 30-year period from 1951 to 1980, is calculated from the temperature normals to be 665 degF-days. This value is termed the mean air freezing index for the area. Distribution of mean air freezing index values for the continental U.S. is given in Figure A1. In the absence of additional information, it is assumed for this study that the mean air freezing index in the future will be similar.

The surface freezing index represents a quantity of heat removed from the ground over a winter season; the loss of this heat causes some of the moisture in the ground to freeze. For moist, sandy soils such as those normally selected to cover the waste materials (see properties, Table A3), calculation based on the procedures described in Aitken and Berg (1968) indicates that the average frost depth for a freezing index of 665 will be about 24 inches when the ground is kept free of snow. A cover of snow reduces the average frost depth, because air held within the snow particles insulates the ground surface. An analysis of the Nashua weather records (described later) indicates that an average of 6 inches of snow remains on the ground in a typical winter. The actual average frost depth in the



DISTRIBUTION OF MEAN AIR FREEZING INDEX VALUES
IN CONTINENTAL UNITED STATES

Figure A1. Distribution of mean air freezing index values in the continental U.S. (Dept. of Army and Air Force, 1985).

Nashua/Hudson area during a winter with a freezing index of 665 and a snow depth of 6 inches would be estimated to be about 12 inches.

It might seem that a soil cover of 12 in. would consequently protect the waste asbestos from freezing. However, 12 in. is not sufficient for the simple reason that average values are normally exceeded for approximately one-half the total time. Thus in about 50 years out of 100 the frost depth will be greater than 12 inches, with the frost zone extending into the asbestos deposit. This is not a safe condition for long-term protection, because the asbestos is likely to be moved by freeze-thaw effects in each of those 50 years.

A reasonable criterion for safe burial is taken to be an air freezing index exceedance level of no more than 10%, representing an average of 10 freezings into the asbestos per century. This criterion is based on the standard used for the design of pavements in seasonal frost areas. Air freezing indices selected for pavement design are usually based upon the coldest year in 10 years or the average for the three coldest years in 30.

In order to determine an air freezing index to be used for asbestos cover design in the Nashua/Hudson area, Nashua air temperature records from the 30-year period 1951 to 1980 were analyzed (U.S. Dept. of Commerce, 1950-1980). To get an idea of the variation of the air freezing index during this period, yearly indices calculated from the mean monthly temperatures were plotted versus a normal probability scale (Fig. A2). Using this plotting method, the 10% exceedance level is about 990 deg F-days.

To determine more accurate values for design purposes, air freezing indices for the coldest winters were calculated from the mean daily temperatures. Table A1 shows the mean freezing indices of the three cold-

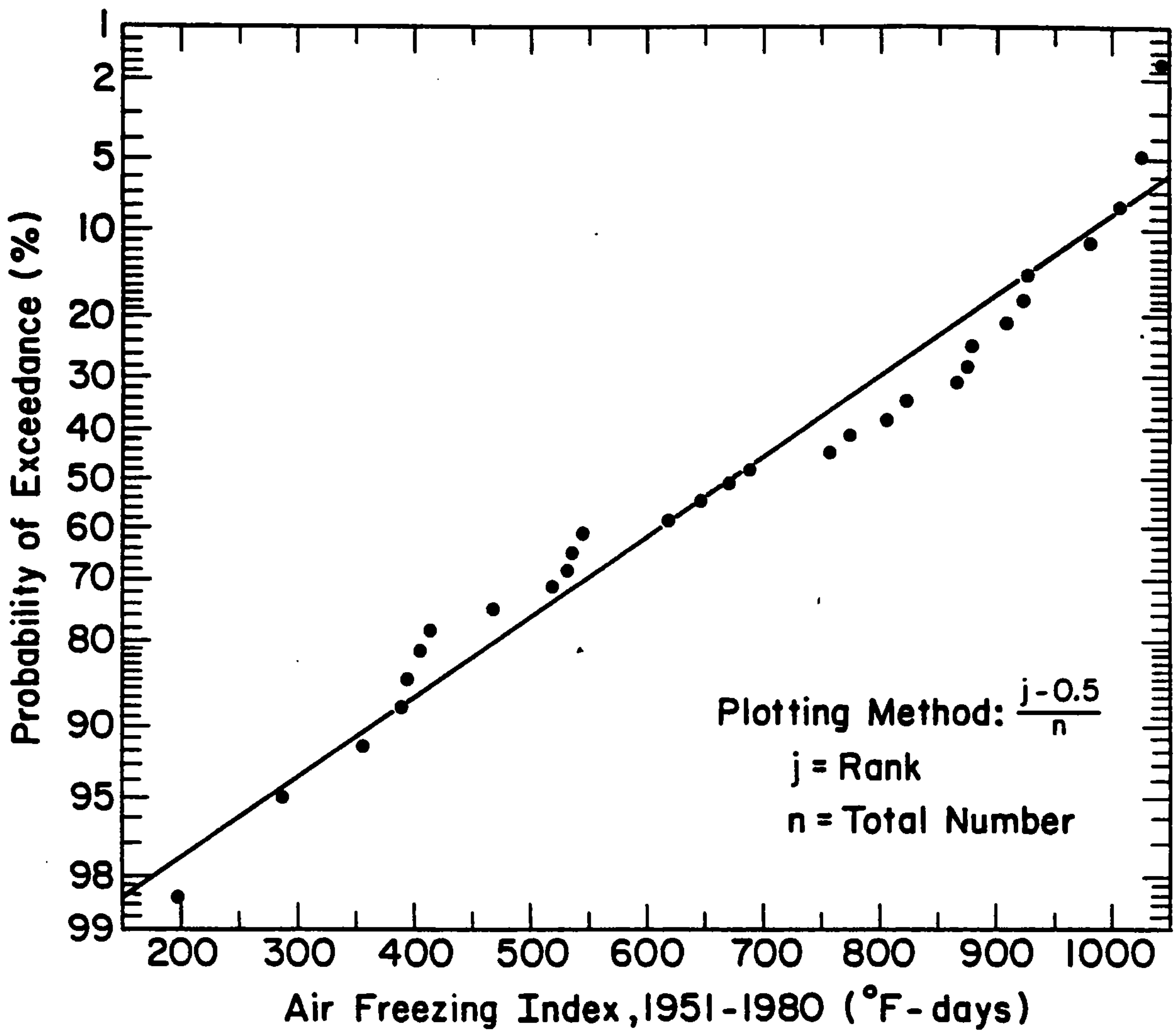


Figure A2. Air freezing indices from Nashua plotted on normal probability paper. Individual points are yearly data calculated from mean monthly temperatures. Solid line indicates cumulative probability of occurrence based on normal distribution.

Table A1. Mean air freezing index for Nashua, New Hampshire (1951-1980).

	Mean Air Freezing Index (deg F-days)	
Condition	Cal. by Daily Mean	Cal. by Monthly Mean
3 coldest in 30	1097	1023
1 coldest in 10	1075	1041

Table A2. Ratios (n-factors) to convert from air freezing index to surface freezing index.

Surface Type	n-Factor
Snow Surface	1.0
Portland Cement Concrete	0.75
Bituminous Pavement	0.7
Bare Soil	0.7
Turf	0.5

est winters in 30 and the coldest winter in 10 as calculated by daily temperatures. These are compared with the equivalent freezing indices as calculated by mean monthly temperatures.

To summarize, design air freezing indices for the Nashua area fall in the general range from 990 to 1100 deg F-days, depending on the procedure used for calculation. Indices determined from daily temperatures, which are higher, are likely to be more representative of actual values. For this reason, the design air freezing index selected for use in determining asbestos cover depths was 1097 deg F-days, the average of the three coldest years in thirty.

To determine depth of frost penetration, one other aspect of winter air temperature data must be examined; that is the length of the freezing season. During calculations of the air freezing index from the mean daily temperatures, this was determined to be about 100 days for the Nashua area.

Surface freezing index

To determine the frost penetration resulting from an air freezing index, one must first estimate the corresponding surface freezing index. The difference between air and surface temperatures at any specific time is influenced by latitude, cloud cover, time of year, time of day, atmospheric conditions, wind speed, surface characteristics, and subsurface thermal properties. However, over an entire freezing season, a single ratio, or "n-factor," can generally be used for various surface types to convert air index to surface index. Table A2 lists the n-factors recommended by Linell and Lobacz (1980).

For simplicity in developing the rationale for this study, an n-factor of 0.5, simulating turf conditions, was assumed for the snow-free case and an n-factor of 1.0 was used when snow was modeled as the cover condition.

Frost Penetration Calculation Procedures

The procedure used to calculate the predicted depth of frost penetration was a multilayered solution of the modified Berggren equation. Detailed discussion of this procedure is found in previous references and only a cursory explanation will be included here (Departments of the Army and Air Force, 1966; Aitken and Berg, 1968; Aldrich and Paynter, 1953). The modified Berggren equation is expressed as:

$$X = \lambda \sqrt{\frac{48\ K\ nF}{L}} \qquad (1)$$

where

X = depth of freeze, ft.

K = thermal conductivity of the soil, B.t.u./ft. hr.°F.

L = volumetric latent heat of fusion, B.t.u./cu.ft.

n = conversion factor for air index to surface index, dimensionless

F = air-freezing index, degree-days

λ = the Lambda coefficient, which takes into consideration the effect of temperature changes in the soil mass.

The Lambda coefficient (λ) is a function of the freezing index, the mean annual temperature of the site, the length of the freeze season, and the thermal properties of the soil. In order to determine a value for the Lambda coefficient, one must solve a transcendental equation by iteration using the error function (Aitken and Berg, 1968; Aldrich and Paynter, 1953).

In modeling frost penetration with the Berggren equation, several assumptions are made. The model assumes one-dimensional heat flow with the entire soil mass at its mean annual temperature prior to the start of the freeze season. In Nashua, the mean annual temperature is 46.4°F (U.S. Department of Commerce, 1985). It is also assumed that when the freezing season starts, the surface temperature changes suddenly (as a step function) from the mean annual temperature to a temperature v_s degrees below freezing and remains at this new temperature throughout the freeze season. The value v_s is the average surface temperatuare differential and is calculated by dividing the surface freezing index by the length of the freeze season, t, in days ($v_s = nF/t$). These calculations also consider latent heat to be a heat sink at the moving frost line, and assume that soil freezes at a temperature of 32.0°F.

When expressed as shown in equation 1, the modified Berggren equation can be used to model the frost penetration depth in one layer of homogeneous soil. When several layers with different soil types are to be modeled, a multilayer solution to the equation is used. The process involves determining that portion of the surface freezing index required to penetrate each layer. The sum of the thicknesses of all the frozen layers is the total depth of freeze. The partial freezing index required to penetrate the top layer is given by:

$$F_1 = \frac{L_1 d_1}{24\lambda_1^2} \left(\frac{R_1}{2}\right)$$

where

d_i = thickness of soil layer, ft.

$$R_i = \frac{d_i}{K_i} = \text{thermal resistance of layer} .$$

The partial freezing index required to penetrate the second layer is

$$F_2 = \frac{L_2 d_2}{24\lambda_2^2}\left(R_1 + \frac{R_2}{2}\right) .$$

The partial index required to penetrate the n^{th} layer is

$$F_n = \frac{L_n d_n}{24\lambda_n^2}\left(\Sigma R + \frac{R_n}{2}\right) ,$$

where ΣR is the total thermal resistance above the n^{th} layer and equals

$$R_1 + R_2 + R_3 \ldots + R_{n-1} .$$

The summation of the partial indexes, $F_i + F_2 + F_3 \ldots + F_n$, is equal to the surface freezing index.

Cover specifications

At the Nashua/Hudson asbestos sites, the majority of the restored area was slated to be revegetated. Therefore, the initial consideration in designing the cover materials was the necessity to support vegetation, specifically grasses.

Because the asbestos waste is extremely alkaline, having a pH of 11 or 12, it is highly toxic to plant life. Therefore, the minimum depth of cover required is that which will be deep enough to keep the grass roots from penetrating the asbestos. Studies have shown that grass roots extend down to 18 inches beneath the surface (Iskandar et al., 1979), so a cover at least that deep is required to assure the long-term survival of the vegetation.

Nutrients are also needed for vegetation survival. It is therefore recommended that the upper 6 inches of cover include topsoil to provide nutrients for the grasses. A 2:1 ratio of topsoil to sand would provide nutrients and allow drainage. Beneath the topsoil, the cover material should consist of a 6-in. layer of fine sand, underlain by an adequate amount of sandy gravel to reduce problems with frost penetration.

In order to determine the amount of gravel to recommend, frost penetration was modeled using a multilayer solution of the modified Berggren equation with a soil profile consisting of 6" topsoil, 6" fine sand, and an indefinite amount of sandy gravel. Table A3 shows the physical and thermal characteristics of the modeled materials for both a wet and a dry case. Properties were chosen so as to be generally representative of the materials at the site. The left-hand portion of Table A4 shows the predicted frost penetration depths at the design freezing index using the soil profile with a variable thickness of gravel.

In the most extreme case, that with no snow, frost penetration is on the order of 34-35 inches. When a snow layer at the surface is included, frost penetration decreases as the snow thickness increases. The next aspect to be considered, then, is what depth of snow cover should be used for the design. The duration of snow cover is another important aspect. However, for the purposes of this design, it was assumed that the duration of snow cover was similar to the length of the freeze season, or about 100 days.

Table A3. Characteristics of Materials Modeled for Frost Penetration.

Layer Type	Moisture Content (%)	Dry Density (pcf)	Heat cap. (Btu/cuft°F)	Thermal Cond. (Btu/fthr°F)	Latent Heat of Fusion (Btu/cuft)
a) Wet Soil					
Topsoil	25	90	32.18	0.85	3240
Sand	15	100	28.25	1.15	2160
Gravel	10	120	29.40	1.59	1728
Asbestos	15	95	26.84	0.68	2052
b) Dry Soil					
Topsoil	18	95	28.62	0.75	2394
Sand	10	110	26.95	1.20	1584
Gravel	10	120	29.40	1.59	1728
Asbestos	15	95	26.84	0.68	2052
c) Snow	0	15	9.50	0.18	0

Table A4. Frost penetration depths predicted by a multilayer solution of the modified Berggren equation using climate parameters typical for Nashua (freezing index = 1097°F-days; mean annual temp = 46.4°F; length of freeze season = 100 days).

Snow Depth (in.)	Frost penetration (in.): Variable cover thickness[1] Soil condition: Dry	Variable cover thickness[1] Soil condition: Wet	30-Inch cover thickness[2] Soil condition: Dry	30-Inch cover thickness[2] Soil condition: Wet
0"[3]	34.4	35.4	33.4	34.0
4"[4]	31.7	30.7	31.3	30.4
6"	24.8	23.0	24.8	23.0
8"	19.8	17.7	19.8	17.7
10"	16.3	13.3	16.3	13.3

[1]soil profile: 6" topsoil
6" fine sand
indef. gravel

[2]soil profile: 6" topsoil
6" fine sand
18" gravel
30" total

[3]n-factor = 0.5 (turf)

[4]n-factor = 1.0 (snow)

Depth of snow measurements were recorded at the Nashua weather station between 1952 and 1976, with some periods of missing data (U.S. Dept. of Commerce, 1950-1980). Complete daily records are available for 15 winter seasons. To get a mean snow depth value for each winter season, the daily depth data between 1 December and 16 March were summed and divided by the number of days. The distribution of these mean seasonal depths are shown in Figure A3. The individual points indicate the yearly data and the solid line shows the cumulative probabilities based on a normal distribution.

The mean snow depth for the 15 years of data is 6.2 inches and the probability that Nashua will have less than this mean amount is 50 percent. As shown in Figure A3, the probability that the mean snow depth will be less than 4 inches is about 25 percent. These two snow depths, then, bracket the amount of snow that might be considered for design purposes.

When the 15-year mean snow depth, 6 inches, is modeled in the Berggren solution, a frost penetration of about 24 inches is predicted (Table A4). Using a 4-inch snow depth, a frost penetration of 30 inches is predicted. For the Nashua/Hudson sites, it was decided to use the 4-inch mean snow depth and the resulting 30 inch minimum cover depth as a final recommendation. This conservative decision resulted from the lack of knowledge about actual rates that asbestos might move through a soil column subjected to cyclic freeze-thaw.

Frost penetration depths were modeled using the Berggren equation with a 30-in. cover (right-hand side, Table A4). Again, material properties used were those shown in Table A3. Because of the lack of actual data, the asbestos properties had to be estimated. The values used were based on the assumption that the top layer of asbestos would have partially mixed with the existing thin topsoil cover. The frost depths predicted by the model

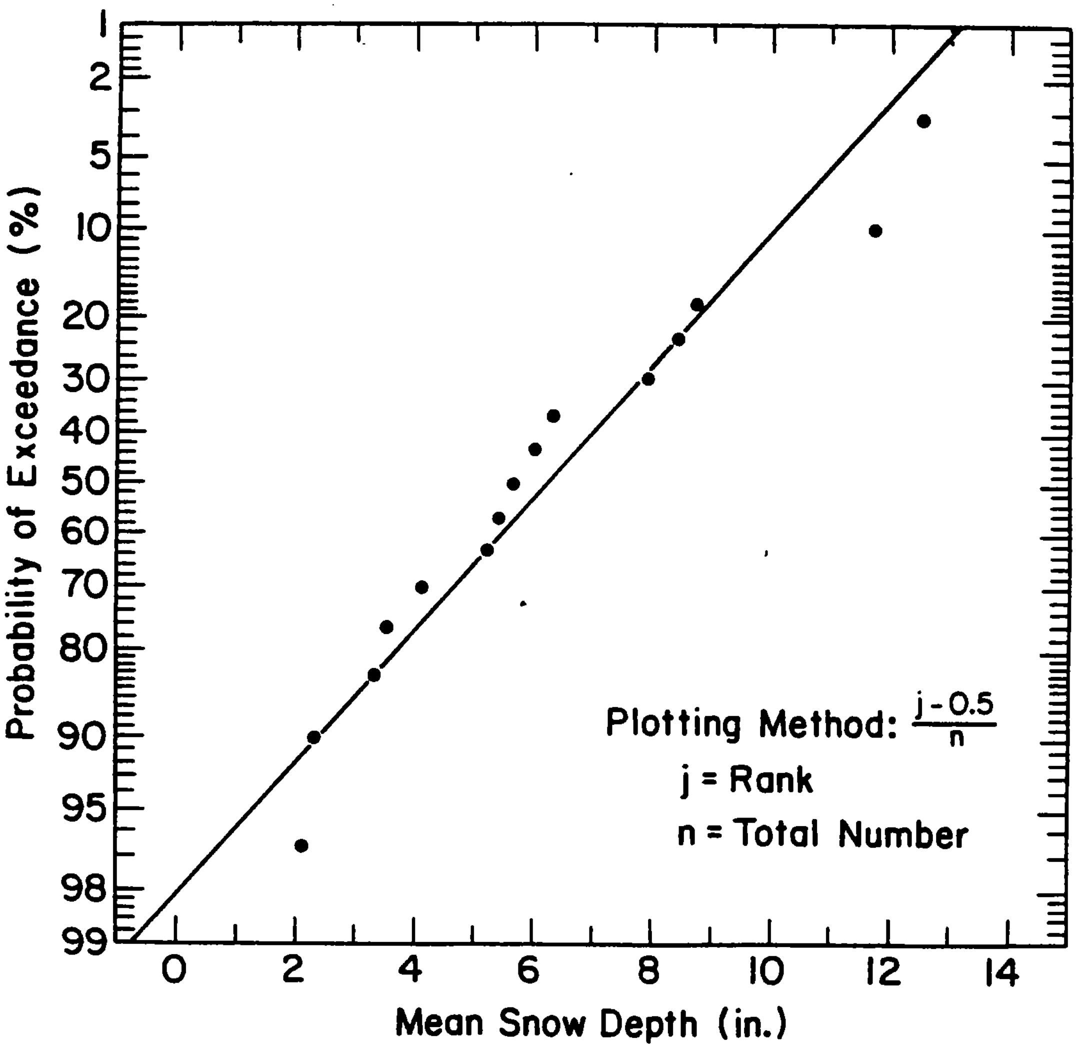


Figure A3. Mean snow depth data from Nashua plotted on normal probability paper. Individual points are the mean snow depth for the winter season 1 December to 16 March. Solid line indicates the cumulative probability of occurrence based on normal distribution.

would penetrate 4 inches of the asbestos in a no-snow year with the design freezing index. In years with a mean snow depth of 4 inches or greater, the frost would be contained in the cover material.

In summary, the thickness of cover recommended at the present time for the restoration of gently sloping terrain at waste asbestos sites in Nashua and Hudson, New Hampshire is 30 inches. This cover should consist of the following three layers from top to bottom: 6 inches of topsoil and sand mixed in a 2:1 ratio, 6 inches of fine sand, and 18 inches of sandy gravel.

Verification

The 30-in. cover determined through modeling with the Berggren solution correlates well with an independent investigation of observed penetration depths compared with freezing degree day accumulations (Haugen and King, in prep.). Figure A4 shows a total of 282 data points observed over a 10-year period at 37 sites within a five-state area (N. Dakota, S. Dakota, Minnesota, Wisconsin and Upper Michigan). The surface conditions at the sites were primarily low vegetative cover or crop rubble. The soil types were quite variable, although most sites were in agricultural fields or in cemeteries, and thus were primarily fine-grained in nature. The snow depth category for these data (based on 3 observations per year) ranged from 0 to 4 inches. An empirical equation for these data was determined to be

$$Y = -6.46228 + 1.02471 \sqrt{X}$$

where Y is frost depth in inches, and X is accumulated freezing degree days (°F) for the season. Its standard error of estimate is 7.5 inches.

When the Nashua design freezing index of 1097 is used in the empirical equation, it predicts a maximum frost penetration of 27.5" ± 7.5". Con-

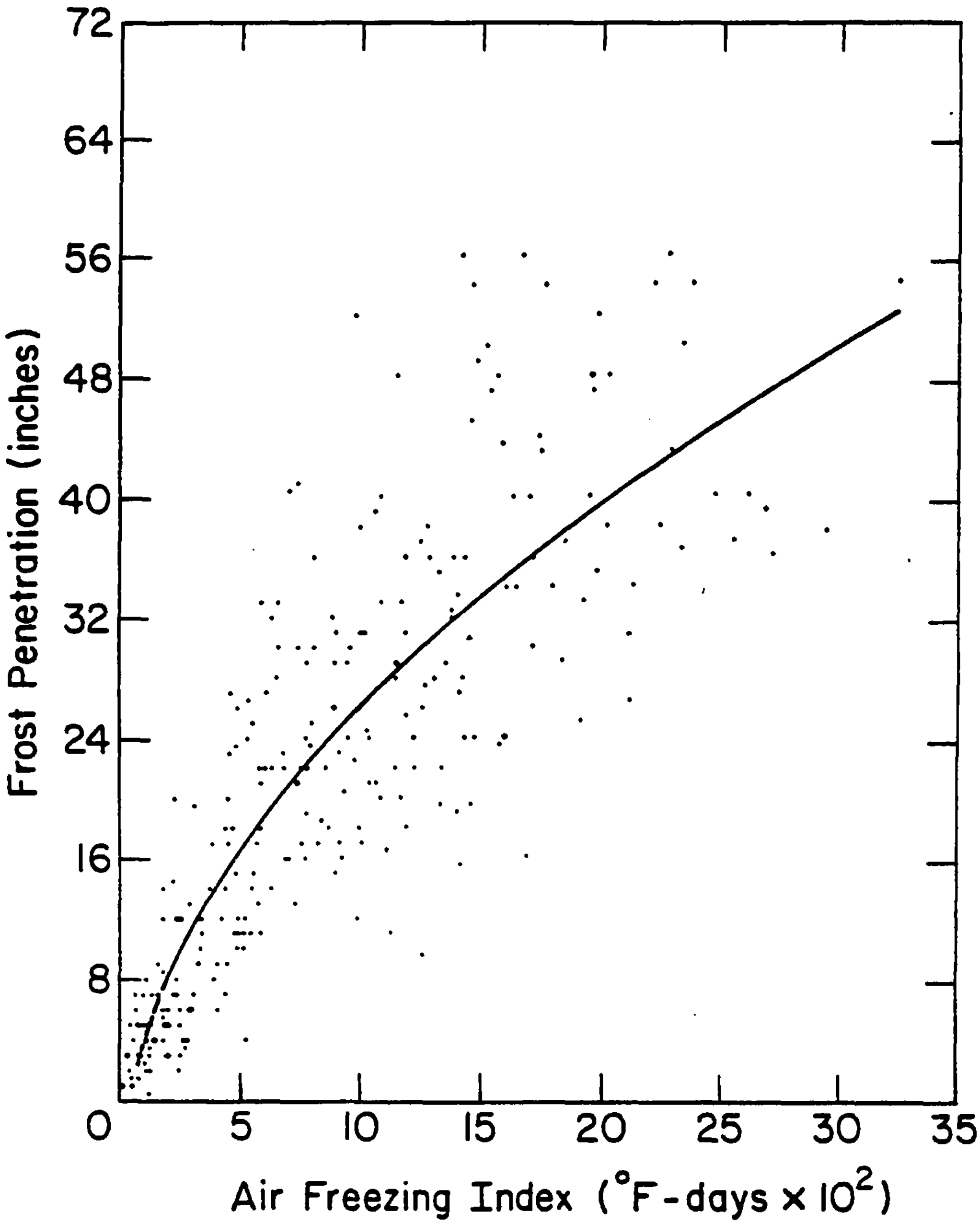


Figure A4. Observed frost penetration depth versus air freezing index (from Haugen and King, in prep.).

sidering that the equation was derived from sites with mean snow depths ranging from 0 to 4 inches, the Berggren solution prediction of 30 inches penetration based on 4 inches of snow is somewhat high. This discrepancy may perhaps be accounted for by the relatively coarse-grained soils, with high thermal conductivities, that were modeled in the Berggren solution for the Nashua site.

Closure

A final, major point to be made relative to the containment of asbestos waste in a natural environment of freezing temperatures is that the minimum depth of cover is not a single value but varies with the climate, the type of soil cover, and the soil moisture conditions. The design referred to here is site specific. The actual thickness of a required cover in the northern areas of the U.S. may be 3-5 feet while in southern areas perhaps only one foot would be needed from the standpoint of frost penetration.

CRREL is not aware of any laboratory or field test information providing data on freeze-thaw caused movement of asbestos material in soils used to cap asbestos waste. It is suggested that the EPA view the covered sites in southern New Hampshire as a case study opportunities for obtaining actual field performance data. These data, along with data from laboratory tests are needed to adequately document this rationale. Once this information has been obtained, a comprehensive document providing sound design criteria for asbestos disposal in seasonal frost areas can be developed.

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